THE PALAEOMAGNETISM OF THE CAINOZOIC BASALTS FROM AUSTRALIA

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Abstract

The magnetic properties of the Cainozoic Volcanics from their type area in Victoria are examined in detail to give the broad picture of the behaviour of the Earth's magnetic field as it existed at the time of extrusion of these Volcanics. On the basis of the direction of magnetization of stably magnetized samples, a clear-cut division is found to exist between the Older Volcanics of Gippsland and the Newer Volcanics of the Western District and, since such a division should be found by sufficient sampling to exist for all other Cainozoic Volcanics, the possibility of this new method for stratigraphical correlation is illustrated by a few palaeomagnetic measurements of Volcanics from elsewhere in eastern Australia.

Numerous specimens from both the Older and Newer Volcanics are found with the direction of magnetization reversed, which is important in geophysical prospecting and may be of value for detailed geological mapping.

The plausible dipole assumption for the steady-state condition of the Earth's magnetic field is used in conjunction with the palaeomagnetic measurements to advance the idea of limited polar wandering during the Cainozoic.

Introduction

In some rocks the directions of remanent magnetization may be identified with the direction of the geomagnetic field at the time and place of deposition, and, in recent years, some success has attended the efforts which have been made to explore the variations in the geomagnetic field in remote ages by measuring in the laboratory the directions of magnetization of rock specimens whose geological age and field orientation are known. Igneous rocks owe their magnetization to the presence of a large number of small particles of ferrimagnetic minerals, usually opaque oxides of the system FeO-Fe_2O_3-TiO_2. These are scattered in a matrix of paramagnetic or diamagnetic minerals such as quartz, amphibole or felspar, which make up the bulk of the rock but which do not contribute to the remanent magnetization. Most of these ferrimagnetic minerals have Curie temperatures between 200 and 700°C., above which they are paramagnetic, and, on cooling down through these temperatures in a magnetic field, they acquire a permanent magnetic moment in the field direction. This is thermoremanent magnetization, and the ferrimagnetic minerals in igneous rocks become magnetized in this way on cooling in the Earth's magnetic field.

The direction of the geomagnetic field is specified by the angles of declination (D) and inclination (I). D is the aximuth of the horizontal magnetic force and is reckoned in degrees east of geographic north. I is the angle between the total magnetic force and the horizontal plane and is reckoned negative if the south-seeking compass direction is below this plane and positive if above it. Nowadays the horizontal component of the geomagnetic field is aligned approximately north-south, so that D is usually small over most of the Earth's surface. The inclination varies between 0° and 90°. It is low near the equator and high in polar latitudes; negative

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in the southern hemisphere and positive in the northern hemisphere. At any one place the field direction undergoes periodic changes through 20° or 30° over hundreds or thousands of years. This is called the secular variation. Although this variation is very complex in detail, the average direction of the field over periods of time of several thousands of years or more at any place of observation is parallel to a line of force in the field of a theoretical dipole situated at the centre of the Earth and directed along the axis of rotation, that is—

$$D = O, \qquad (1)$$

and

$$\tan I = 2 \cot \theta \qquad (2)$$

where θ is the co-latitude of the place of observation. Some thousands of years is a very short period compared with the time taken for a thick rock formation to accumulate, so that the average magnetic direction of many specimens selected so as to span the thickness of such a formation is this dipole field direction, and the effect of secular variation is averaged out.

This communication gives an account of palaeomagnetic work on some of the Cainozoic volcanic rocks of Australia. It contains complete experimental data, and its main object is to discuss the possible uses of this work in aiding geological correlations. Other papers (Irving and Green, 1957a, b) deal more specifically with the geophysical aspects and attempt an integration with equivalent results from elsewhere in the world.

The Cainozoic lavas of Australia are for the most part olivine basalts, and cover an area of approximately 50,000 square miles, mainly in the eastern states. In Queensland. New South Wales, South Australia, Victoria and Tasmania their position within the Cainozoic, in general, cannot be fixed with any great accuracy, but in Victoria, where there is often contact with fossiliferous sediments, they are more adequately dated and may be divided into two main groups (Singleton, 1939) which differ in age, petrology (Edwards, 1937, 1938) and geomorphological relationships (Hills, 1938). For this reason, sampling has been concentrated in these two groups, which are known as the Newer and Older Volcanics of Victoria.

The Newer Volcanics have a more or less continuous outcrop to the west of the meridian of Melbourne. They overlie the marine Tertiaries of this region and cannot be older than Pliocene—in fact, it is certain that the bulk of the lavas belong to the Pleistocene—but it is possible that some of the earlier flows are Pliocene in age. The youngest flows are geologically Recent. The Newer Volcanics have been faulted in places, but tilting of the lava field has been negligible.

The Older Volcanics, sometimes called the Narracan Volcanics, outcrop mainly to the east of Melbourne and are interbedded with non-marine sediments which form part of the Tertiary sequence in Victoria. In the area sampled they are believed to represent a single stratigraphic entity which is certainly Lower Tertiary in age and probably Eocene. This Lower Tertiary sequence has been deformed by later Tertiary movements, but these have not been extensive and steeply dipping beds are restricted to the neighbourhood of faults and monoclinal folds. There is no metamorphism. The present discontinuous outcrops have resulted from erosion subsequent to this deformation.

Both groups have been extensively sampled and show two important features:

1. Within each group the average direction of magnetization regardless of sign remains approximately constant, but repeated reversals of polarity occur. Sometimes the magnetizations are normal (—ve) with the south

pole directed below the horizontal plane, and sometimes reversed (+ve) with the north pole downwards.

2. In the Newer Volcanics the average direction of magnetization has an inclination of 59·8°, whereas in the Older Volcanics the mean inclination is 13·1° steeper.

These two features are referred to, respectively, as reversals and change of the average direction. Reversals occur several times within each group, whereas the change from the steep inclination in the Older Volcanics to the lower value in the Newer Volcanics is a much slower process. Reversals may be interpreted (there are alternative explanations) as indicating reversals in the sign of the geomagnetic field, but the change in direction of magnetization between different rock formations is thought to be due to an entirely different geophysical process, namely, a change in the attitude of the mean magnetic axis of the Earth relative to the outer layers (Creer et al., 1954). The directions in the Newer Volcanics are such as could have been acquired in the field of a geocentric dipole whose axis, which will be called the mean geomagnetic axis, coincides with the present axis of spin. On the other hand, the mean geomagnetic axis consistent with the magnetization of the Older Volcanics is at an angle of 23·2° to this.

In the other states of the Commonwealth, attempts by purely geological methods to extend the two-fold division established in Victoria have been successful to some extent, but in many cases it is impossible to define ages with any degree of certainty. The difference in direction between the Older and Newer Volcanics in Victoria should exist in basalts of earlier and later Cainozoic age elsewhere, so that palaeomagnetic data may be of assistance in stratigraphic correlation. The possibilities of this method are illustrated by comparing some magnetic results from basalts in Queensland, New South Wales and Tasmania with the "standard" results from Victoria.

Experimental Methods

Fresh hand specimens were taken mostly from quarries, road cuttings and sea cliffs. Thirty microscope slides were examined to test for incipient weathering which may not be detectable in hand specimens. In all cases the outlines of the iron minerals were clean and there was no indication of weathering which could have altered the initial magnetic properties.

The hand specimens were orientated prior to extraction from the rock face by standard geological techniques. Cylinders were machined from these with non-magnetic tools, orientation being preserved during the process. The directions of magnetization and susceptibility of these cylinders were measured on the magnetometer described previously (Irving, 1956a).

The method used here of conducting a palaeomagnetic survey of volcanic formations with optimum sample economy has been described previously (Watson and Irving, 1957). For the general survey of the Victorian lavas, samples have been taken from as many sites as possible spread over the outcrop, with two or three samples at each to minimise experimental error. In this way inhomogeneities due to the secular change of the geomagnetic field and geological tilting are averaged out, and a wider regional picture is obtained than would otherwise be the case if the same number of samples were distributed among fewer sites. Errors due to geological tilting have been reduced to a minimum by using only those sites at which the beds are known to be flat-lying or dipping by less than 5°. The effect

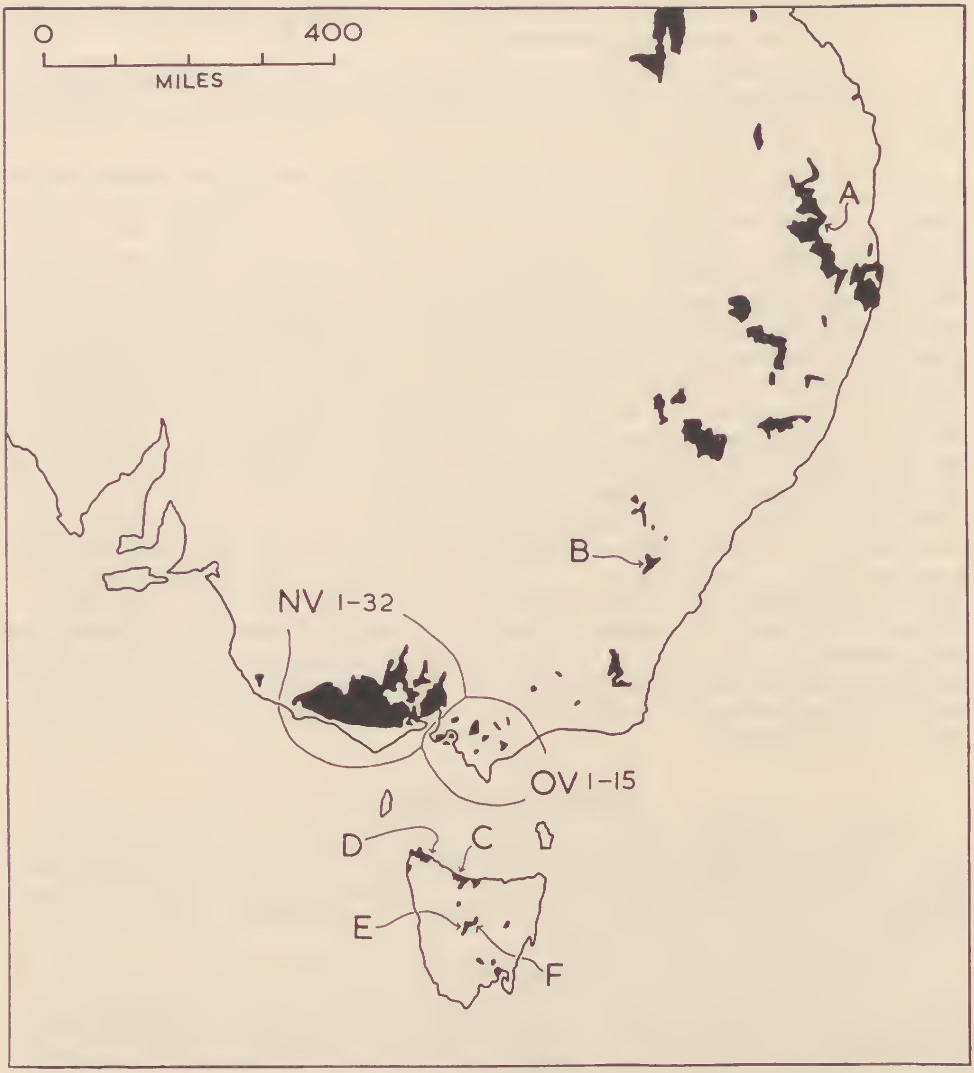

Fig. 1.—Sketch map of south-eastern Australia showing the outcrop of the Cainozoic volcanics and the areas sampled.

of this will be lost in any case when results from many localities are averaged, and the present horizontal will be a close approximation to the horizontal at the time of deposition.

The areas from which collections were made are shown in Fig. 1. Locality and sampling details are listed in Table 3. The distribution of sites in Victoria is shown in Fig. 2, and the region in the neighbourhood of Melbourne in greater detail in Fig. 3. In the Newer Volcanics, 2 samples were taken at each of 30 sites and the

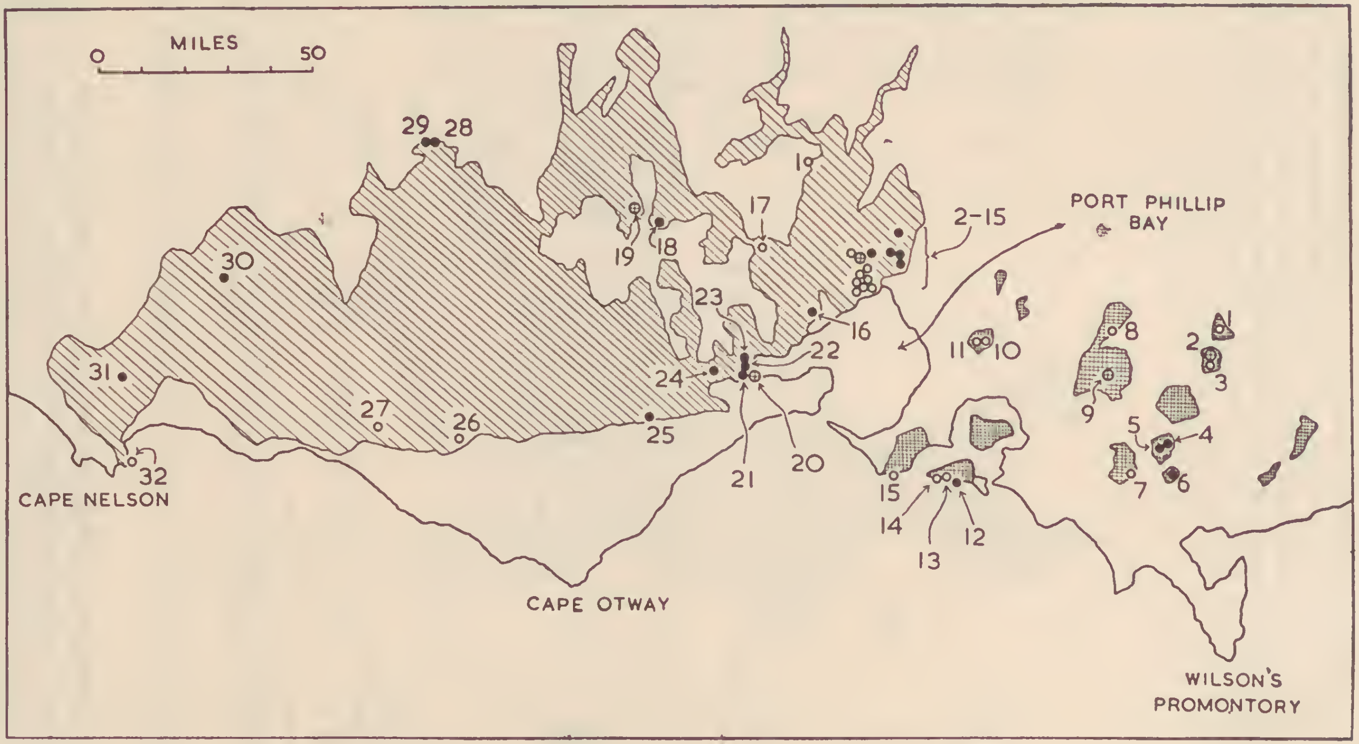

FIG. 2.—Distribution of sampling sites in Victoria. The outcrop of the Older Volcanics is indicated by cross-hatching and that of the Newer Volcanics by oblique shading. The sites are numbered as in Table 3. Sites with normal, reversed, and mixed polarities are indicated by circles, dots, and circles with crosses, respectively.

area covered is approximately 10,000 square miles; 2 sites (NV10, NV15) were sampled in detail to test for consistency within a single lava flow. In the Older Volcanics only 15 suitable sites were found and, because of this, 3 samples were usually obtained at each. The coverage is about 5,000 square miles. Outside Victoria

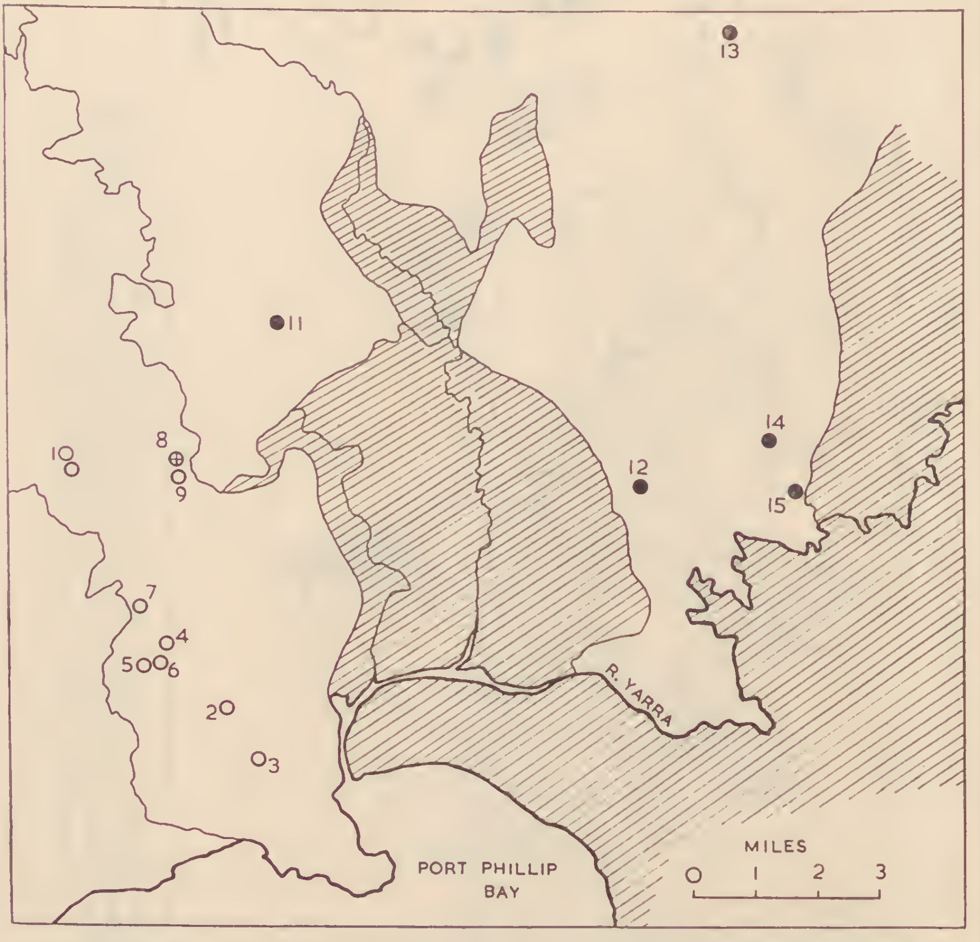

FIG. 3.—Distribution of sampling sites in the Newer Volcanics of the Melbourne area. The basalt outcrop is left blank, and the sites are numbered and marked as in Fig. 2.

the collecting sites are scattered over eastern Australia, 2 or more samples being obtained at each.

The Directions of Magnetization of the Victorian Lavas

The directions of magnetization are shown on equal-area projections in Figs. 4 to 7. The plane of the projection is always the horizontal plane and plotting is always on the upper hemisphere. The degree of uniformity at 2 quarries is illustrated in

Fig. 4. There is good agreement at the individual sites and irrespective of sign there is reasonable agreement between sites.

The mean directions at 32 sites in the Newer Volcanics are plotted in Fig. 5; 13 sites have the polarity of the present field (north-seeking polarization upwards) and 16 are of opposite polarity, the two groups being exactly 180° apart; 3 sites have mixed polarity. The overall mean direction, regardless of sign, is parallel to the geocentric axial dipole field (Table 1, Fig. 7). The mean site directions in

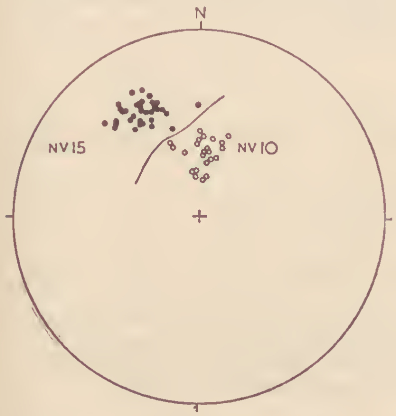

Fig. 4

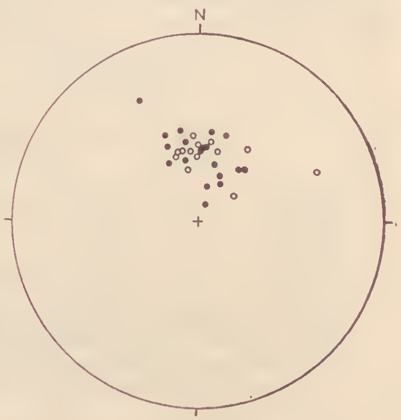

Fig. 5

Fig. 4.—The directions of magnetization at Albion Quarry, Sunshine (NV10) and at Adam's Quarry, Alphington (NV15). North-seeking directions are indicated by circles (normal) and south-seeking directions by dots (reversed).

Fig. 5.—The mean directions of magnetization at 32 sites in the Newer Volcanics of Victoria. Sites with normal directions indicated by circles, and those with reversed directions by dots. Sites with mixed polarities are indicated by crossed circles.

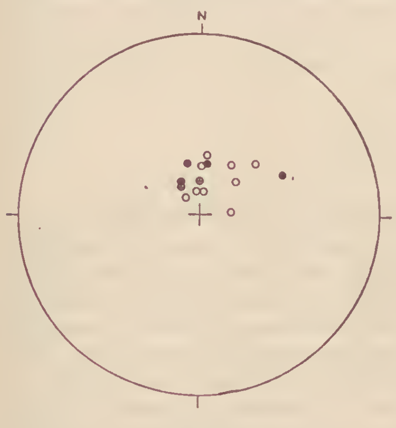

Fig. 6

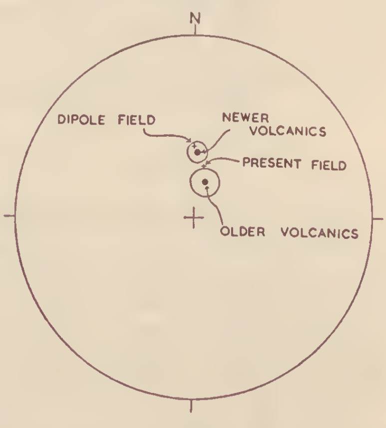

Fig. 7

Fig. 6.—The mean directions of magnetization at 15 sites in the Older Volcanics of Victoria. Legend as for Fig. 5.

Fig. 7.—The average directions of the Newer and Older Volcanics of Victoria. The average directions of magnetization are indicated by dots with error circles at $P = 0{\cdot}05$. Present field direction shown by crosses.

the Older Volcanics are given in Fig. 6; 9 sites have negative inclination, 4 are positive, and 2 sites have mixed polarity. The data are insufficient to test the exactness of these reversals. The average direction of the whole group, regardless of sign, is given in Table 1 and Fig. 7. The inclination is steeper than in the Newer Volcanics and the declination is easterly.

TABLE 1

The Directions of Magnetization in the Victorian Volcanics and the Pole Positions consistent with these Directions

	Average direction of magnetization			Sampling area		Pole position			
	D	I	α P=0·05	Lat.	Long.	Lat.	Long.	δ m P=0·05	δ p P=0·05
Newer Volcanics	3·4	−59·8	4·8	38·0S	143·5E	86·3S	102·1E	7·2	5·5
Older Volcanics	15	−72·9	6·8	38·0S	145·5E	66·8S	122·7E	12·1	10·8

D and I are the declination and inclination of the average directions. α is the Fisher error (Fisher, 1953) calculated from a modified formula (Watson and Irving, 1957). The pole positions are specified by latitude and longitude; δ p and δ m are the pole errors in the direction of and at right angles to the colatitude (Irving, 1956a).

The occurrence at 5 sites (Fig. 2) of mixed polarities is a matter of some interest. Contiguous samples with opposed polarities have been noticed previously in these basalts by Rayner (private communication). Three possible explanations may be given:

1. At each of these sites several lava flows, although not distinguishable, may in fact be represented, so that the specimens can have cooled through the Curie temperature at different times between which the magnetic field reversed.
2. Self-reversal processes of the type mentioned later under "Reversals of Magnetism" may have operated.
3. Errors in orientation may have occurred despite the great care taken to avoid them.

The Position of the Pole in the Past relative to Australia

It has been pointed out in the introduction that the average direction of magnetization of a rock formation is parallel to a line of force in the Earth's dipole field. From this average direction the axis of this dipole field may be calculated and also the positions of the points or poles at which this axis intersects the Earth's surface (Irving, 1956b). The pole positions consistent with the directions of magnetization of the Older and Newer Volcanics are given in Table 1 and plotted in Fig. 8.

The pole for the Newer Volcanics coincides with the present geographic pole, showing that the Earth's magnetic field during the past million years has been, so far as this part of the world is concerned, on average that of a geocentric axial dipole. The Older Basalt pole is on the fringe of the Antarctica and much nearer Australia. Previous work on the dolerite sills of Tasmania (Irving, 1956a) and the lavas and glacial varves of the Kutfung Series of New South Wales (Irving, 1957a, b) has defined the pole positions for the Jurassic and Upper Carboniferous. They lie in what is nowadays the region of the Tasman Sea and, with the Older Volcanic pole, fall consecutively on a path leading in a broad sweep to the pole for the Newer Volcanics and the present geographic pole. Since the magnetic and rotational poles have coincided during the past million years, it may be suspected that they always have been coupled together, so that the path in Fig. 8 is also the path of the geographic pole relative to Australia. Evidence in support of this view is found in the deposits of glacial origin which occur in the Upper Carboniferous in many parts of Australia. These deposits indicate frigid conditions such as are most

Fig. 8.—The position of the pole relative to Australia in the past. The pole positions are numbered as follows: 1 Newer Volcanics of Victoria, 2 Older Volcanics of Victoria, 3 Tasmanian dolerite sills, 4 Kuttung Volcanics, 5 Kuttung sediments.

likely to have arisen in a high geographic latitude, just as the palaeomagnetic results indicate a high geomagnetic latitude. Theoretical reasons connected with the origin of the geomagnetic field also suggest that the two poles will always have coincided (Runcorn, 1954). The evidence in Fig. 8 would suggest therefore that in Carboniferous times the south geographic pole was just to the east of Australia and has since moved gradually away, reaching its present position during Upper Tertiary times.

Reversals of Magnetization

Reversed magnetizations were noticed first in the Cainozoic basalts of Australia by Mercanton (1926) in 3 specimens from Queensland, and again by Rodgers (1952) in 4 specimens from the Armidale region, and by Almond, Clegg and Jaeger (1956) in one bore-core specimen from Tasmania. Rayner (1937, 1940) has inferred from local anomalies in the geomagnetic field in central New South Wales and New England that the directions in underlying basalts are in some cases reversed. In addition to these and the reversals in Victoria, the authors have found reversely magnetized basalt at Toowoomba in Queensland and at Berrima in New South Wales (see Table 3).

Reversals of magnetization could result either from complex processes affecting the iron minerals (Neel, 1951) or from reversals in sign of the Earth's magnetic field without change in direction of the dipole axis. Both may have occurred. The first and, so far, the only laboratory demonstration of self-reversal properties in a naturally occurring rock has been given by Nagata et al. (1952) for a dacite from Mt. Haruna in Japan. This rock possesses a reversed natural remanent magnetization and, when cooled from above the Curie temperature in the Earth's field, takes on a magnetization parallel to this field but opposite in sense. Six specimens of reversed basalt from Victoria, when treated in the same manner, acquired a magnetization with the same sense as this field, as is the case in all re-heating experiments so far conducted on basalts from elsewhere in the world. This would seem to suggest that these basalt reversals reflect a change in sign of the geomagnetic field, but it must be recognized that during re-heating experiments the delicate self-reversing property may be destroyed and such tests are not therefore decisive.

Reversed magnetizations are a characteristic feature of the Cainozoic volcanics of Australia just as they are in equivalent lavas in the Northern Hemisphere, but until more field and laboratory data are available from them it is impossible to say whether or not they indicate reversals in sign of the geomagnetic field in Australia during the Cainozoic.

Application of Palaeomagnetism to Problems in Geological Correlation

Reversals may, in future, be of some assistance for the relative dating of beds within a rock formation. For instance, if the whole of the lower part of a rock formation is reversed whereas the upper is normal, the magnetic polarity becomes a characteristic of considerable value for correlation purposes. As often happens, however, beds with reversed and normal magnetizations alternate in serial fashion, so that the occurrence of a reversed magnetization in a specimen of unknown age does not allow it to be allocated to any specific level. A survey of all the known outcrops of the Newer Volcanics, paying attention to the polarity only, could be achieved very quickly and may be of help in mapping these lavas whose detailed chronology is at present so uncertain.

The changes in average direction of magnetization are more important for correlation purposes. From the pole positions given in Fig. 8, it is possible in principle to predict the average direction of the geomagnetic field for any part of Australia during any of the epochs represented. The directions observed in rocks of unknown or doubtful age may be compared with these theoretical values and a probable age allotted on this basis. Just as rock formations of a certain age may be identified by a fossil or fossil assemblage, they may also be identified by a certain direction of magnetization which arises from the geomagnetic pole being in a certain position relative to Australia during the time of deposition. Since the rate of polar movement relative to Australia is slow even on the geological time scale, the dating by this method is not as precise as that achieved by palaeontology, and although it ought to be possible to assign a rock group to a particular epoch, in general, it will not be possible to place it in one of the sub-divisions of that epoch. Consequently, the greatest application of this method is in unfossiliferous rock formations, notably in the Pre-Cambrian and in igneous rocks of younger date. Measurements are now being made to extend the curve in Fig. 8 back into the Pre-Cambrian, and when this is completed a method of the greatest assistance to Pre-Cambrian chronology will be available.

Although the Cainozoic basalts of Victoria can be dated for the most part with some accuracy, the dating of these basalts elsewhere in Australia is far from satisfactory. By comparing the directions of magnetization in these basalts against the "standard" directions found in Victoria, some information about their age may be provided. As an illustration of this method, directions observed in basalts from New South Wales, Tasmania and Queensland are used. Inclinations only are compared, since the difference between the Older and Newer Volcanics is largely one of inclination. The co-latitudes for the collection area relative to the Newer and Older Volcanic poles are obtained by calculation (or graphically from Fig. 8) and the theoretical inclination is then obtained from equation (2). These values are listed against the observed inclinations in Table 2. The basalt of Berrima in New South Wales

TABLE 2

Comparison of Observed Inclinations with the "Standard" Values from Victoria

(Localities are marked in Fig. 1 and Table 3.)

Locality	Theoretical inclination deduced from the Victorian results		Observed Inclination
	From the Newer Volcanics	From the Older Volcanics	
A	49	65	43
B	56	70	71
C	62	74	78
D	62	74	80
E	62	74	69
F	62	74	54

(site B) has a large magnetic inclination (71°) very much steeper than that predicted for this region in Upper Pliocene and Quaternary times by results from the Newer Volcanics of Victoria (56°), but is similar to that anticipated for this region from the Older Volcanic data (70°) suggesting that it is comparable in age with the later. The basalt has been deeply dissected and duri-crusted, and a Lower Tertiary age is favoured on these grounds (David and Browne, 1950, p. 575). The palaeomagnetic and geological evidence is consistent, and the case for these basalts being of Lower Tertiary age is thereby greatly strengthened.

Near Wynyard in Tasmania (site C), a hillside excavation by Mr. M. R. Banks exposed a basalt beneath a Miocene limestone. The steep magnetic inclination in this indicates a Lower Tertiary age which is in agreement with the geological evidence.

The magnetic inclination in the basalt of Circular Head, Tasmania (site D), is steep, suggesting a Lower Tertiary age. Petrologically this basalt is similar to the Older Volcanics of Victoria (Edwards, 1940) and the field evidence, although not definite, is not inconsistent with a Lower Tertiary age.

The basalt of Skittle Balls Plain near the Great Lake, Tasmania (site F), has a moderate inclination indicating an Upper Tertiary or Quaternary age. This is consistent with the geological work of Voisey (1949) who regards these basalts as post-dating the main faulting in the region which Carey (1946) suggests in early Miocene.

The basalt at Clarence River, Tasmania (site E), gives a direction between the two predicted values. The geological indications of its age are also uncertain.

The basalts of Toowoomba, Queensland (site A), have an inclination appropriate to an Upper Tertiary or Quaternary age. This is contrary to the geological evidence which suggests that they are Lower Tertiary (David and Browne, 1950, p. 572).

At 4 sites (B, C, D, E), the palaeomagnetic and geological evidence is in agreement; at site A they are contradictory, and at site F both lines of evidence are indefinite. At each site only a small period of time is represented, so that errors due to the secular change of the Earth's magnetic field will arise. This may account for the result at site F. For a similar reason the palaeomagnetic evidence at site A may be in error, although in this case the geological dating is doubtful. The other four results are satisfactory, and it seems probable that a full palaeomagnetic survey of the Cainozoic basalts in the states of the Commonwealth (other than Victoria), when used in conjunction with geological evidence, will provide an improved basis for dating these formations.

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TABLE 3

Directions and Intensities of Magnetization, and Susceptibility

(This table contains the primary data. Sites are designated as follows: Older Volcanics of Victoria OV1-15, Newer Volcanics of Victoria NV1-32, and sites in other states A to F. D_i and I_i are the declinations and inclinations of each individual specimen, D_s and I_s are the declinations and inclinations of the site mean directions. Reversed, normal and mixed polarities are signified by R, N and X respectively. M is the remanent magnetic intensity in e.m.u. $\times 10^4$ per c.cm. χ is the magnetic susceptibility, being the ratio of the intensity of magnetization in e.m.u. $\times 10^4$ per c.cm. induced by an external field to the strength of that field, in this case 0·9 oersted.)

Site Number	Locality	Map	Grid Ref.	D_i	I_i	D_s	I_s	Polarity	M	χ
OV1	Jacob's Ck. Quarry, 8 m. S. of Walhalla	Moe 1″	438 400E 313 900N	24 39 28	−72 −48 −70	33	−63	N	19·5 13·3 25·9	0·4 0·7 0·6
OV2	S.E.C. Quarry, N. of Yallourn	Moe 1″	434 700E 299 600N	353 157 12	−77 +77 −71	0	−75	X	12·2 7·2 11·3	5·9 6·0 3·6
OV3	S.E.C. Quarry, N. of Yallourn	Moe 1″	434 900E 299 500N	358 6 321	−80 −81 −77	345	−80	N	8·9 7·6 9·9	3.2 3·9 2·8
OV4	True Blue Quarry, 1 m. WSW. of Mirboo North	Mirboo North 1″	412 500E 265 100N	153 167 173	+65 +66 +58	165	+63	R	35·6 31·6 37·3	10·1 2·3 0·7
OV5	Quarry on Berry's Ck. Rd., SW. of Mirboo North	Mirboo North 1″	407 500E 263 500N	160 140	+75 +71	149	+73	R	31·5 57·6	4·5 3·5
OV6	Hillside Quarry, 2 m. SW. of Mirboo	Mirboo North 1″	417 600E 253 700N	240 248 244	+42 +52 +49	244	+48	R	10·7 18·9 10·3	4·6 6·6 6·6
OV7	Chalmers Hill Quarry, 3 m. E. of Leongatha	Korumburra 1″	399 900E 255 200N	333 24	−82 −76	1	+80	N	67·7 63·8	29·3 20·8
OV8	Jindivick Quarry, N. of Warragul	Drouin 1″	391 600E 309 400N	337 7 24	−63 −66 −73	0	−69	N	14·9 10·9 23·1	5·0 5·2 8·2
OV9	Quarry at Drouin South	Drouin 1″	387 600E 294 700N	325 110 160	−76 +80 +66	324	−75	X	10·1 12·3 14·6	10·1 29·0 50·3
OV10	Bayview Quarry, Berwick	Cranbourne 1″	336 500E 310 900N	59 59 30	−55 −62 −49	48	−56	N	12·6 10·4 7·7	1·3 3·8 1·7
OV11	Second Quarry, nr. Berwick	Cranbourne 1″	336 300E 310 800N	14 8 354	−66 −61 −61	6	−63	N	22·4 23·4 37·4	16·5 19·9 18·8

OV12	Sea cliff nr. Pyramid rock	Woolamai 1″	325 800E 249 800N	166 189 205	+63 +69 +58	188	+64	R	12·5 5·7 14·7
OV13	Evans Quarry, Phillip Is.	Western Port 1″	325 100E 255 100N	281 19	−72 −79	319	−80	N	39·8 15·5
OV14	Sea cliff, Phillip Is.	Woolamai 1″	218 100E 252 600N	28 59 55	−69 −79 −57	47	−69	N	15·4 10·2 24·5
OV15	Sea cliff between Flinders and Cape Schanck	Sorrento 1″	290 200E 254 300N	80 58 133	−78 −67 −78	85	−76	N	8·4 11·3 4·4
NV1	Quarry nr. Turritable Falls, Mt. Macedon	Lancefield 1″	262 600E 385 500N	33 36	−42 −60	34	−51	N	6·1 7·6
NV2	Quarry nr. Forestry Commission's depot, Newport	Melbourne 1″	290 700E 234 700N	347 347	−58 −58	347	−58	N	10·5 12·7
NV3	Operating Quarry at Newport	Melbourne 1″	291 800E 333 300N	359 95	−66 −60	55	−71	N	7·5 77·4
NV4	Highfield Quarry, West Footscray	Melbourne 1″	288 900E 336 400N	332 349	−60 −59	340	−60	N	8·0 11·2
NV5	Lord's Quarry, Geelong Rd., Braybrook	Melbourne 1″	288 500E 335 800N	358 350	−56 −49	356	−52	N	6·8 15·3
NV6	Willis Quarry, Geelong Rd., Braybrook	Melbourne 1″	288 700E 335 900N	358 358	−56 −65	358	−61	N	10·1 24·7
NV7	Stanley Quarry, Market St., Braybrook	Melbourne 1″	288 200E 337 500N	8 9	−53 −55	9	−54	N	4·6 6·4
NV8	Regal Quarry, Duke St., Braybrook	Melbourne 1″	289 100E 341 700N	18 255	−49 +63	41	−59	N	15·8 5·0
NV9	McGrath's Quarry, Duke St., Braybrook	Melbourne 1″	289 200E 341 500N	338 352	−50 −60	343	−58	N	7·1 38·5
NV10	Albion Quarry, Sunshine	Melbourne 1″	286 200E 341 400N	359 11 15 4 8 0 3 20 4 18 9 6 10	−56 −64 −63 −63 −66 −52 −54 −52 −62 −58 −61 −60 −55	0·3	−61·8	N	3·9 2·9 3·8 3·5 3·5 0·6 0·6 0·6 0·6 1·6 0·6 0·8 0·6

					17	−56				0·6	0·6
					10	−72				4·3	0·4
					354	−70				4·1	0·5
					4	−74				4·0	0·5
710					354	−72				4·2	0·6
nt.	Albion Quarry, Sunshine	Melbourne	286	200E	351	−70	0·3	−61·8	N	2·9	0·6
		1″	341	400N	338	−55				10·5	0·6
					339	−57				12·8	0·5
					358	−58				5·5	2·3
					347	−61				6·7	1·0
711	Fowler's Quarry, Keilor R., North Essendon	Sunbury 1″	291	800E	145	+50	157	+54	R	1·7	3·9
			345	700N	173	+57				2·3	5·7
712	Merri Ck. Quarry	Melbourne 1″	302	300E	203	+68	192	+74	R	6·9	4·8
			341	400N	183	+80				5·4	5·0
713	Paramount Quarry, Epping	Yan Yean 1″	304	800E	158	+51	158	+49	R	18·3	5·8
			353	100N	158	+46				20·5	6·7
714	Rock Quarry, Station St., Fairfield	Ringwood 1″	305	700E	173	+51	168	+49	R	88·6	20·0
			341	200N	164	+46				120·0	56·6
					144	+31				13·5	7·1
					150	+31				9·7	5·4
					150	+25				9·3	5·9
					150	+35				13·7	7·0
					142	+41				34·1	9·3
					158	+39				26·5	19·0
					136	+33				9·6	2·2
					134	+30				10·5	3·3
					143	+36				139·0	1·9
					150	+33				29·9	2·6
					150	+41				24·7	0·9
					148	+31				28·8	0·9
					137	+32				16·5	5·9
					143	+26				20·7	6·6
					143	+29				18·7	3·4
					150	+34				17·3	6·6
					133	+29				13·4	3·4
715	Adams's Quarry, Yarralea St., Alph-	Ringwood	307	000E	143	+30	149·6	+34·9	R	16·1	6·9
	ington	1″	341	000N	147	+41				22·9	7·7
					147	+41				30·9	8·2
					147	+41				31·0	8·9
					152	+39				46·2	13·6
					157	+38				41·6	10·3
					161	+41				49·4	12·0
					152	+41				37·7	10·1
					161	+39				39·3	8·1
					151	+31				29·7	9·5
					153	+38				29·3	9·5
					156	+34				33·6	10·0
					156	+36				26·3	9·9
					154	+26				17·9	5·9
					158	+35				19·0	6·6
					156	+30				15·3	5·1
					178	+40				58·0	1·6

NV16	Werribee Quarry, Werribee	Melbourne 1″	263 900E	177	+68	177	+62	R	26·5
			319 400N	177	+57				22·4
NV17	Reservoir Quarry, Bacchus Marsh	Ballan 1″	248 100E	21	−57	15	−58	N	40·0
				8	−54				36·2
			351 800N	16	−62				33·9
NV18	Dunnstown Quarry, Dunnstown	Ballarat 1″	203 400E	150	+50	152	+61	R	7·5
			360 800N	158	+73				8·5
NV19	Council Quarry, Alfredton, Ballarat	Ballarat 1″	189 700E	22	−48	18	−50	X	9·4
			365 300N	192	+52				14·2
NV20	Marnoch Vale Quarry, Geelong	Geelong 1″	240 300E	182	+60	16	−64	X	24·5
			293 600N	33	−60				33·8
NV21	Minn's Quarry, Fyansford, Geelong	Geelong 1″	237 400E	185	+61	181	+59	R	6·9
			295 000N	178	+56				7·9
NV22	Fyansford Quarry, Fyansford, Geelong	Geelong 1″	237 500E	178	+58	183	+57	R	5·7
			295 600N	188	+57				25·4
NV23	Mobile Quarry, Fyansford, Geelong	Geelong 1″	237 700E	148	+52	170	+54	R	22·4
			296 000N	192	+53				34·8
NV24	Pollacksford Quarry, Pollacksford Bridge	Geelong 1″	226 900E	179	+56	185	+57	R	13·5
			295 800N	192	+57				26·7
NV25	Armytage Quarry, Armytage	Colac 1″	196 100E	241	+85	202	+82	R	3·9
			278 400N	190	+77				4·2
NV26	Cobden Quarry, Cobden	Colac ¼″	597E	56	−43	68	−31	N	30·4
			247N	76	−19				42·0
NV27	Framlingham Rd. Quarry, Framlingham	Panmure 1″	563 200E	24	−75	348	−67	N	30·5
			276 100N	332	−55				19·0
NV28	Ararat Ck. Quarry, Ararat	Ballarat ¼″	593E	213	+64	205	+68	R	4·6
			395N	194	+71				9·3
NV29	Barret's Quarry, Ararat	Ballarat ¼″	592E	209	+58	210	+71	R	9·0
			396N	211	+85				6·4
NV30	Menzel's Quarry, Hamilton	Penshurst 1″	501 500E	191	+43	188	+50	R	16·4
			342 100N	184	+57				17·7

31	Porter's Quarry, Heywood	Heywood 1″	459 000E	211	+63	217	+61	R	6·7	5·8
			302 500N	222	+60				6·6	1·6
32	Portland Harbour Trust Quarry, Portland	Portland 1″	461 200E	3	−53	359	−56	N	21·9	2·6
			268 200N	8	−37				5·4	0·2
				348	−45				3·8	3·3
				348	−84				4·5	1·9
	The Main Range Toowoomba, Queensland	Toowoomba 1″	506 700E	175	+35	187	+43	R	1·2	5·6
			1578 000N	196	+24				1·3	3·3
			and	177	+26				6·1	10·1
			506 100E	182	+38				23·6	15·4
			1579 100N	157	+53				1·1	3·5
				277	+59				5·1	3·5
	Road cutting on Hume Highway 3 m. NE. Berrima, New South Wales	Mittagong 1″	334 100E	174	+73	208	+71	R	45·6	12·2
			741 100N	231	+64				15·2	4·4
	Seabrook Ck. E. of Wynyard, Tasmania	Devonport ¼″	379E	44	−84	50	−78	N	42·0	5·2
			948N	53	−73				41·9	5·7
	Circular Head Quarry, Stanley, Tasmania	Smithton ¼″	335E	10	−77	50	−80	N	35·2	25·7
			980N	90	−76				42·7	27·4
	Road cutting nr. Clarence R. and Bridge on Tarraleah Bronte Rd., Tasmania	Queenstown ¼″	438E	16	−72	344	−69	N	5·2	3·2
			807N	324	−63				10·8	1·3
	Road cutting—Missing Link Rd., Skittle Balls Plain, Great Lake, Tasmania	Devonport ¼″	458E	11	−57	5	−54	N	9·4	1·3
			830N	0	−50				5·9	2·3